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Coronary artery bypass surgery with intermittent aortic cross-clamping

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Abstract. Despite the generally accepted use of cardioplegia for myocardial protection during cardiac revascularization and other operations, non-cardioplegic methods have been used by many surgeons throughout the world. We have prospectively studied 229 patients consecutively subjected to isolated coronary artery bypass surgery from March 1990 to February 1991 by a single surgeon who used intermittent aortic cross-clamping for construction of the distal anastomoses. The mean age of the patients was 58.9 ± 8.9 years. One hundred and nine patients (47.6%) with unstable angina were subjected to urgent or emergent surgery and 129 (56.3%) had a previous myocardial infarction. The mean number of grafts per patient was 3.0. The ischaemic time per graft was 6.5 ± 1.4 min. At least one internal mammary artery was used in 98% of the cases (1.4 internal mammary artery grafts/patient). Hospital mortality was 0.9% (two patients, in neither case related to the procedure). Only nine patients (3.9%) required inotropes and none needed intra-aortic counterpulsation. The analysis of serum enzymes specific of myocardial lesion showed a CPK-MB/CPK ratio of 10.5 ± 10.2 after surgery, 6.4 ± 6.6% at 24 h after surgery, and 6.9 ± 2.6% by the 5th day. Only four patients (1.7%) had ECG criteria of myocardial infarction. These results were compared retrospectively with those of the 40 immediately preceding patients (December 1989 to February 1990), in whom crystalloid cardioplegia had been used. There were no differences between the two groups with regard to age, prevalence of unstable angina and of previous myocardial infarction, and technique used. The mean aortic cross-clamp time was 50.0 ± 11.5 min. There was no mortality in this group and four patients (10%; p = NS) required inotropic support. One patient (2.5%) sustained a myocardial infarction. There were no differences in enzyme levels to those in the former group. These results, in a non-selected group of patients, appear to demonstrate that intermittent aortic cross-clamping for short periods (< 10 min) affords good myocardial protection and is a simple and safe method to use during revascularization procedures. [Eur J Cardio-thorac Surg (1992) 6:189–194]

Key words: Coronary surgery – Intermittent aortic cross-clamping – Cardioplegia

Since the late 1970s, hypothermic hyperkalaemic cardioplegia has been used by most surgeons for myocardial protection during coronary artery bypass surgery and other cardiac procedures [17, 21]. Several modifications of the original crystalloid solutions and of the techniques of delivery have been experimented and used clinically. Nevertheless, a great deal of controversy still exists with regard to the potassium content [12], temperature (cold or warm) [15], vehicle (crystalloid or blood) [3] and method of administration (antegrade or retrograde [6], multidose or continuous [13]). The multitude of methods and techniques is, perhaps, the clearest indication of the inadequacy of all of them.

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However, non-cardioplegic methods are still used during coronary surgery by many surgeons throughout the world [1, 2, 5, 10, 19]. They include ventricular fibrillation with local control of coronary blood flow and intermittent aortic cross-clamping. The arguments in favour of non-cardioplegic techniques include their greater simplicity and, in the case of intermittent aortic cross-clamping, the proven capacity of the myocardium to withstand short periods of ischaemia, intercalated with periods of physiological perfusion, without necrosis or detectable impairment of function [23].

Having used cardioplegia until recently, we have now utilized intermittent aortic cross-clamping for myocardial protection during coronary artery bypass surgery since February 1990. In this paper, we report on the experience we obtained with this method during the first 12 months. We also compare some of the clinical and laboratory data with those of the preceding 40 patients, taken as the control group, operated on with the use of cardioplegia.

Material and methods

Patients

During the 12-month period to the end of February 1991, 229 consecutive patients, all operated on by the same surgeon, were subjected to isolated coronary artery bypass surgery using intermittent cross-clamping of the aorta (Table 1). Another 27 patients who underwent associated procedures, such as valvular replacement or repair, closure of ventricular septal defects and excision of ventricular aneurysms, performed with the use of cardioplegia, were, by definition, not included in the series. The mean age of the 213 male (93.0%) and 16 female patients was 58.9 ± 8.9 years (range 30–80 years); 52 (22.7%) were more than 65 years old.

Eighty-five patients (37.1%) had unstable or pre-infarction angina and were operated on as urgent cases. Additionally, 24 patients (10.5%) had emergent surgery. A history of previous myocardial infarction was recorded in 129 patients (56.3%), including 19 (8.3%) whose infarction had occurred in the 30 days preceding surgery. As to the severity of the coronary disease, 160 patients (69.9%) had triple, 40 (17.5%) had double and 8 (3.5%) had single vessel disease, while 21 (9.1%) had left main stem occlusion. Twenty-seven patients (11.8%) had severe left ventricular dysfunction (EF < 0.30).

Surgical technique

The technique used was essentially that previously described by Bonchek and Burlingame [5]. We detail only some technical aspects related to this method. Cardiopulmonary bypass was instituted with a bubble (89%) or membrane oxygenator and non-pulsatile flow, and patients were cooled to an oesophageal temperature of 30 °C. A left ventricular vent was introduced through the right superior pulmonary vein. The first distal anastomosis was immediately constructed to the right coronary artery or to its posterior descending branch, when required. Second were generally the anastomoses to the vessels of the circumflex system and last were those to the anterior descending artery and its diagonal branches.

The aorta was cross-clamped just before the beginning of each anastomosis, but only after the anastomotic site on the coronary artery and the end of the vein or arterial graft had been prepared. In a significant number of cases, where there was little flow through the coronary artery, it was possible to perform the anastomosis without clamping the aorta. Sequential anastomoses were performed during separate clamping periods and these were not allowed to exceed 10 min. When a longer time was required, the clamp was removed and the anastomosis continued, if possible, with control of blood flow with coronary occluders. Occasionally, a second period of cross-clamping was necessary.

The proximal anastomosis of each graft was constructed immediately after the distal one, except when the latter was performed without clamping, in which case a second distal anastomosis was often constructed. Usually, reperfusion periods lasted 5–6 min, while the proximal anastomoses were performed. Dead times were used for preparation of the anastomotic sites and of the grafts.

The distal anastomoses of arterial grafts were constructed last. Usually, the left internal mammary artery was grafted to the anterior descending artery, with sequential anastomoses to its diagonal branches. When required, the right mammary was used, either as a pedicled graft to the proximal right coronary, or as a free graft to the distal segment of this vessel, or to the branches of the circumflex artery. As a rule, and if the anatomy was favourable, double mammary artery grafting was done in patients younger than 60 years of age. The proximal anastomoses of arterial grafts were performed directly to the aortic wall, except in the few cases where it was significantly thickened, in which case a small venous patch was interposed.

Ventricular fibrillation often occurred with manipulation of the heart. For construction of the right coronary graft, the heart was allowed to continue beating, except when an endarterectomy was required. Conversely, for anastomoses on the back of the heart, fibrillation was induced electrically if it did not occur spontaneously. Generally, asystole occurred towards the end of each cross-clamping period and normal beating ensued after removal of the aortic clamp. Otherwise, the heart was defibrillated electrically, although we have lately tended to allow it to continue fibrillating rather than use multiple electrical shocks. In the vast majority of cases spontaneous sinus rhythm resumed after the last period of clamping.

Bloodless prime was used if the haematocrit was greater than 40%, and blood was not given unless the haematocrit dropped below 25% during cardiopulmonary bypass. Towards the end of the procedure, all blood remaining in the oxygenator and tubing was given back to the patient. Mediastinal blood shed in the first 6 h in the intensive care unit was collected in the cardiotomy reservoir, as described by Cosgrove et al. [9], and reinfused manually as required.

Analysis

Control group. The clinical data and the results of the patients of the study group were compared retrospectively with those of the 40 patients whose surgery immediately preceded the use of intermittent aortic cross-clamping and in whom multi-dose cold crystalloid cardioplegia was used (Table 1). These patients were operated on by the same surgeon, using the same techniques except for the method of myocardial protection. The mean age was 57.1 ± 8.3 years (range 39–76 years; p = NS). There were no differences with regard to sex distribution, incidence of unstable angina (20%), previous myocardial infarction (65%), and type of coronary disease (62.5% triple vessel disease) and left ventricular function (12.5% severe dysfunction).

Definitions. Early death was defined as death within 30 days of operation or during the same hospital admission, whichever was longer. Inotropic support was the use of any vasoactive amine for the treatment of low cardiac output for longer than 12 h. Myocardial infarction was diagnosed by ECG criteria alone, by the observation of new Q waves.

Biochemical analysis. Blood samples were collected upon arrival in the intensive care unit, and on the 1st and 5th postoperative days, for laboratory measurement of serum enzymes indicative of cell damage: creatine kinase (CK) and its MB fraction, lactic dehydrogenase (LDH) and transaminases (SGOT and SGPT). The ratio CK-MB/total CK, taken as specific of myocardial lesion, was determined for all patients, but no specific value was taken as indicative of myocardial infarction.

Statistical analysis. All continuous data are expressed as mean ± standard error of the mean, except when indicated otherwise. Dif-

Table 1. Clinical data of patients in both the study and the cardioplegia (control) group

	Intermittent aortic cross-clamping	Cardioplegia
No. of patients	229	40
Sex		
M	213 (93.0%)	37 (92.5%)
F	16 (7.0%)	3 (7.5%)
Age (years)		
mean	58.9	57.1
range	30–80	39–76
Unstable angina	85 (37.1%)	8 (20.0%)
Previous AMI	129 (56.3%)	26 (65.0%)
Type of disease		
3 vessels	160 (69.9%)	25 (62.5%)
2 vessels	40	14
1 vessel	8	1
LV dysfunction (EF < 0.30)	27 (11.8%)	5 (12.5%)

AMI = acute myocardial infarction; LV = left ventricular; EF = ejection fraction; p = NS throughout

ferences between groups were evaluated by the one-tailed Student t-test for continuous data and by χ^2 analysis, with 2×2 contingency tables, for discrete data, and were considered significant at p values equal to or less than the 0.05 level.

Results

Study group

Internal mammary artery grafts were used in 224 patients (97.8%), including 39 patients (17.0%) in whom both left and right internal mammary arteries were used, for a total of 319 anastomoses (1.4 per patient) (Table 2). Additionally, 374 venous anastomoses (1.6 per patient) were constructed. Hence, an average of 3.0 coronary artery branches were bypassed per patient. Endarterectomies were performed in 57 patients (24.9%), 50 of the right coronary and 7 of the left system. The average aortic cross-clamp time per graft was 6.5 min (range 0–9 min), adding to a global clamp time of 24.2 ± 13.4 min (range 0–68 min). The cardiopulmonary bypass time was 71.1 ± 21.6 min (range 15–145 min).

There were two early deaths (0.9%), in both cases related to poor preoperative condition and coronary anatomy rather than to the operative technique or the myocardial protection. The first patient was a 67-year-old man who had severe left ventricular dysfunction and poor vessels and required five grafts which were constructed during 29-min global cross-clamp and 95-min bypass times. He had no signs of perioperative infarction but died on the 6th postoperative day of respiratory failure which he had preoperatively. The second patient was also 67 years old and had a recent myocardial infarction and moderate left ventricular dysfunction. He had four grafts with cross-clamp and bypass times of 21 min and 89 min, respectively. He left the operating room in complete atrioventricular dissociation and low cardiac output. He had irreversible brain damage with decerebration and died on the 35th postoperative day.

No patient required intra-aortic counterpulsation and only nine (3.9%) needed inotropic support, three of them (1.3%) for longer than 24 h. Besides the patient who died, another one left the operating theatre in complete atrioventricular dissociation which recovered after a few hours. Four patients (1.7%) had ECG criteria of perioperative myocardial infarction but none had significant haemodynamic consequences. No other serious complications were observed.

Control group

Internal mammary artery grafts were constructed in all but one of the 40 patients of this group. The mean number of distal anastomoses per patient was 3.2 (range 1–6; p = NS vs. study group) of which 1.4 were internal mammary artery grafts. The mean cross-clamp time was 50 ± 11.5 min, corresponding to 15.6 min per graft.

There were no operative deaths in this group. No patient required intra-aortic counterpulsation and four (10.0%) needed inotropic support (p = NS). One patient (2.5%) had a documented myocardial infarction without haemodynamic imbalance.

Table 2. Operative data and results

	Intermittent aortic cross-clamping (range)	Cardioplegia (range)
No. distal anastomoses/patient	3.0 (1–5)	3.2 (1–6)
No. IMA grafts/patient	1.4	1.4
Aortic cross-clamp (min)	24.2 (0–68)	50.0 (8–89)
Time/distal anastomosis (min)	6.5 (0–9)	15.6
Cardiopulmonary bypass (min)	64.5 (15–145)	61.7 (18–160)
Mortality	2 (0.9%)	0
Inotropic support	9 (3.9%)	4 (10.0%)
Myocardial infarction (ECG)	4 (1.7%)	1 (2.5%)
Temporary AV dissociation	2 (0.9%)	9 (22.5%)

IMA = internal mammary artery; AV = atrioventricular

Table 3. Enzyme values (CPK-MB/CPK ratio)

	Intermittent aortic cross-clamping	Cardioplegia
After surgery:		
mean	10.48 ± 10.23	7.67 ± 9.85
range	0.17–24.70	0.91–23.97
12–18 h postoperatively:		
mean	6.45 ± 6.60	5.81 ± 6.35
range	1.23–25.00	1.23–25.10
5th day postoperatively:		
mean	6.90 ± 2.62	7.60 ± 1.80
range	3.75–9.89	5.70–9.49

p = NS

Biochemical analysis

The levels of serum enzymes were identical in both study and control groups, immediately after surgery and on the 1st and 5th postoperative days. Only mild, mostly non-significant, elevations were observed in the non-cardioplegic group, especially in the immediate postoperative values of the CK-MB, which had dropped to normal 1 day after the operation (Table 3), and in the values of the LDH (892 ± 470 IU/l immediately postoperatively and 838 ± 357 IU/l on the 5th postoperative day; p = NS (study group vs. control).

Discussion

When it was reintroduced in the mid-1970s, cardioplegia was almost instantly recognized as a major advance in myocardial protection for most open heart procedures and was preferred by most cardiac surgeons. Until then, valvular and congenital operations necessitated long periods of aortic cross-clamping and consequently myocardial ischaemia [16]. Periods in excess of 20 min were a constant practice which, in the light of more recent knowledge, caused irreversible damage to a significant number of myocardial fibres. However, shorter periods of ischaemia, alternating with adequate periods of reperfusion, have been demonstrated to be compatible with

good preservation of the myocardium [23]. Hence, comparing the results of modern-era cardioplegia with old age intermittent aortic cross-clamping is unrealistic.

Coronary artery bypass surgery lends itself quite easily to non-cardioplegic methods as it does not require "opening the heart" and its targets, the coronary arteries, are superficially located. All that is required is adequate control of residual or collateral blood flow, and this can be achieved by a variety of methods, including brief periods of aortic cross-clamping. Akins [1] has reported excellent results with the use of fibrillatory arrest of the ventricles and direct local control of blood flow. This method is an important part of the technique we are now using, as many anastomoses can be entirely or partly done without clamping. In this case, however, we prefer to control the flow of blood through the artery being grafted with the coronary sizers or, lately, the Florester occluders. [1]

It is worth stressing other technical aspects. First, efficient decompression of the left ventricle is essential, and we feel that direct venting via the right superior pulmonary vein and left ventricle is preferable. Second, the periods of cross-clamping must be strictly controlled and kept below the 10-min mark. Ideally, reperfusion periods should match the ischaemic periods or be as long as possible without creating unnecessary dead times. When the latter are unavoidable, they must be utilized fully for the construction of the proximal anastomoses and for the preparation of the next venous or arterial graft as well as the next distal anastomotic site. Intelligent management of ischaemic and reperfusion periods, including full utilization of the cooling and warming periods, makes the procedure shorter than with cardioplegic techniques, although our extracorporeal circulation times were very similar with both methods. Third, intermittent aortic cross-clamping is compatible with associated procedures such as endarterectomies, which are more easily done with the aorta clamped, and repair of left ventricular aneurysms, which is very easy without clamping. Fourth, van der Veen and co-workers [24] have recently demonstrated, by biochemical methods, no additional benefit from hypothermia (25 °C) in the myocardial preservation during coronary artery bypass procedures with intermittent aortic cross-clamping. Accordingly, we lower our patients' temperature only to 30° – 32 °C and feel that this attitude may minimize the effects of lower temperatures in the peripheral vascular resistances. Although hypothermia was always considered an important component of the techniques of myocardial preservation [8, 22], normothermic cardioplegia has recently been introduced [14, 20], apparently with improved results which may be due, at least partially, to the same effects.

As can be inferred from the discussion above, intermittent aortic cross-clamping is an easy method to use in coronary artery surgery. It reduces the amount of operative gear, thus making the operative field more manageable, and reduces the cost of disposables, although this fact may not be of universal concern. However, there are several other advantages in the method. It avoids the haemodilution which results from multi-dose crystalloid cardioplegia and, to some extent, from blood cardioplegia. It also does not affect the circulating factors as much and therefore has a positive influence on the perioperative blood loss. Because of that, it contributes to reducing the amount of blood utilized. In our experience, less than 20% of patients required blood or its derivatives.

Another important point to consider is that contact between hyperkalaemic solutions, sanguineous or assanguineous, and the endothelium of both the native coronary arteries and of the grafts, whether veins or arteries, is avoided. The deleterious effects of high concentrations of potassium over endothelial cells of vein grafts have been clearly demonstrated [7]. The use of large doses of cardioplegic solutions for prolonged periods of time, especially during continuous cardioplegia, may have adverse consequences to the durability of grafts, yet to be determined.

One the other hand, there remains some concern about the incapacity of cardioplegic solutions to reach myocardial territories beyond critical coronary artery obstructions [4]. Retrograde cardioplegia has been introduced specifically to provide more even distribution of cardioplegia, but this technique is clearly more cumbersome and may have other consequences to the coronary veins and the myocardium [18]. Also, the presence of a significant non-coronary collateral blood flow washes out the cardioplegia and decreases its capacity to protect the myocardium [6]. The implications of this fact are especially evident in reoperations with patent internal mammary artery grafts.

The experience reported here confirms that of other surgeons that intermittent cross-clamping is a safe and efficient method of preservation of the myocardium during coronary artery bypass surgery. In the absence of other secure indicators of myocardial lesion, clinical performance is an acceptable method of assessment of the adequacy of the protection. Flameng et al. [10] have demonstrated good clinical performance after coronary bypass surgery with intermittent aortic cross-clamping, despite a better preservation of high-energy phosphates, glycogen, and myocardial ultrastructure in patients in whom cardioplegia was used. Our mortality rate of under 1% is lower than that we had in the patients previously operated on with the use of cardioplegia, even though we are now operating on sicker patients with more severe coronary disease. A better indicator of the adequacy of myocardial protection may be the low usage of inotropic support, which was required in only nine of our patients (3.9%), while none needed intra-aortic balloon pumping, having in mind that 12% of patients had severe left ventricular dysfunction preoperatively and that 8% had a recent myocardial infarction. We also feel that the fact that virtually all patients returned to the intensive care unit in sinus rhythm, in contrast with our previous experience with cardioplegia, indicates good myocardial preservation [11].

In the beginning, it was important to make sure that the decision to change to the new method was correct. Consequently, we decided to compare the results with those of a control group constituted by the last 40 patients operated on with the use of cardioplegia. Since there had been no other changes in the technique and the clinical characteristics of the patients of the two groups were identical, we feel that the comparison is warranted.

[1] Bio-Vascular, Inc., St. Paul, Minn., USA

Although there was no difference in the perioperative mortality, there was a greater need for inotropic support in the cardioplegic group, which also had a much higher percentage of patients leaving the operating room in atrioventricular dissociation. The comparison between the two groups of patients included the study of serum enzymes, especially those considered specific of myocardial lesion. Although there was a slight increase in the CK-MB in the non-cardioplegic group, this did not reach statistical significance and was only observed in the samples collected immediately after surgery, which probably confirms the transient and reversible characteristics of the ischaemia.

In conclusion, we have not shown a definitive clinical superiority of intermittent aortic cross-clamping over the cardioplegic techniques of myocardial protection, mainly because of the low morbidity and mortality rates observed in both groups, but the method has proven simpler, safe and efficient. In our hands it has resulted in smoother immediate postoperative periods, presumably an index of better myocardial performance. It certainly constitutes an alternative which could be used advantageously in specific circumstances, even by surgeons who regularly utilize cardioplegia.

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Discussion

Dr. H.B. Barner (*New Hyde Park, NY, USA*). *Dr. Antunes* has reported an impressive experience with intermittent aortic cross-clamping for myocardial revascularization. Most of us used this technique until the advent of cardioplegia, and some of us have returned to it because of simplicity, reduced cost and results comparable to those obtained with cardioplegia.

Dr. Antunes has utilized cross-clamp intervals of less than 10 min, which attests to his technical prowess, and he has emphasized the importance of keeping cross-clamp intervals no longer than this. Brief ischemia times are important with this technique, particularly with a myocardial temperature of 30°C. It is probably not appropriate to ask if a systemic temperature of 25° or 27°C might be beneficial in view of his results, but I would ask if imposition of such time constraints is appropriate for resident training or would he alter his technique for this purpose?

He emphasizes the importance of a ventricular vent, which was used by a minority of surgeons during the intermittent clamping era, but is used by Bonchek and associates. Dr. Antunes, do you merely vent into the pericardium or do you use gravity of suction drainage? If the latter, do you take precautions to retrieve air from the ventricle?

It is clear that the hemodilution, which occurs with crystalloid cardioplegia, and to a lesser degree with blood cardioplegia, is avoided. The hyperkalemia of cardioplegia may injure endothelium of grafts and native coronaries, but there are data to suggest that this is not a problem.

Perhaps the bottom line is that the experience reported is that of a single surgeon with remarkable skills and that this approach, while entirely appropriate in such hands, will not be so forgiving in the face of longer ischemic intervals which are repeated and, therefore, cumulative.

Dr. Antunes: Thank you, *Dr. Barner*, for your remarks. In the early days of intermittent cross-clamping, periods in excess of 20 min, which we know now are very damaging to the myocardial fibers, were common practice. Hence, it is not realistic to compare today's results of cardioplegia with those of the past. A very important principle to adhere to is not to allow cross-clamping times to exceed the safe values. With regard to the temperature, there has been some work demonstrating that lower temperatures add very little, especially with short cross-clamp times.

Naturally, this raises the problem of the training of less experienced people and, of course, one has to have in mind the characteristics of each specific surgeon. I do not intend to say that this method should be used for all patients, although it has worked well in our hands and I continue to use it routinely. Each surgeon will have to define his own indications. In some cases, such as reoperation for a new single graft in a patient with a patent IMA, this could well be the method to use.

We vent through the right superior pulmonary vein, LA and mitral valve in every single patient. However, because the method is completely closed, I do not take any special care in extracting air from the ventricle, as it is usually not there.

Finally, this technique has helped us to avoid hemodilution; we are very happy with the very low blood consumption we have achieved, and we think that is an important factor in its favor.

Mr. J. D. Parker (*London, UK*). Thank you very much. I enjoyed your contribution. As a surgeon who has used intermittent cross-clamping going back to the 1970s, I have never found it necessary to vent, I think, with very rare exceptions. I think if one keeps a careful watch on distention of the graft, you can avoid that. However, I think that to restrict it to 10 min is going to be unnecessarily restrictive in applying this technique. I would like to ask you one or two points about your technique. There are two important principles involved.

I think the pharmacological management of the heart prior to the operation is important. I personally will always use beta blockers and calcium antagonists and nitrates, too, unless there is a strong contraindication to do that, and continue it right up to the time of operation. I believe they are important like other protective agents, particularly calcium antagonists. There is a whole lot of experimental evidence to support that.

Secondly, if you do use this technique and go beyond 10 min, I think it is important to have a reperfusion period that is at least 50% of the ischemic time, and I would be interested in knowing whether you would like to have the heart beating or whether it is fibrillating during that intermittent period. I personally have chosen to keep the temperature to 31 °C and have the heart beating while the top end of the anastomosis is being done. Thus, I think those are all important points in this technique, and I would value your comments.

Dr. Antunes: Well, as we gained experience, we realized that we can take longer times, but at beginning we didn't want to take any chances. I completely agree with you that the longer the operation and the more cross-clamping periods we use for the whole operation, the longer we need to keep our reperfusion periods, but there has never been a waste of time. To take advantage of the intervals between clamping, we prepare the next vein graft or the mammary artery. Before clamping again one can open the coronary artery, probe it and even place the suture material through the heel or tip of the graft, whatever the case may be.

We do use pharmacological preparation of the heart, especially the nitrates, but not so much calcium or beta blockers.

I prefer to have the heart beating during the proximal anastomoses, and many distal anastomoses can be performed with the heart beating. It often happens that during the clamping period, the heart goes from fibrillating to beating. In the end, virtually 90% of the patients come back directly into sinus rhythm after the last anastomosis.

Dr. F. Fontan (*Bordeaux, France*). *Dr. Antunes*, maybe I misunderstood the slide referring to the effect of temperature on oxygen consumption. If I understood you correctly, this slide referred to an arrested heart, and in an active heart, either fibrillating or beating, the effect of cross-clamping the aorta is probably different.

I would also like to draw your attention to the fact that in simple aortic cross-clamping, each period of aortic cross-clamp is followed by a period of reperfusion. There are many experimental data that show that even after a period of 30 s or 1 min, there may be lesions due to injury reperfusions. Of course, that cannot be obvious in the clinical setting and in the results, but that does not eliminate the problem. Could you comment on these points?

Dr. Antunes: Yes, I will. There was a recent report from The Netherlands on experimental work designed especially to verify the effects of lowering temperature during intermittent aortic cross-clamping. The authors could not demonstrate any additional protection by lowering the temperature from 32° to 25 °C.

I realize that the data I have presented is not based on good markers for myocardial lesion. However, we surgeons are used to trusting the performance of the patients, especially in the postoperative period. For the moment, I am happy with the results.

As we went along the study and looked for references, we were astonished at the very significant number of surgeons throughout the world who are using this technique. Very few talk about it, but I believe that the technique is yet another alternative for at least some specific cases.

Dr. D. A. Cooley (*Houston, TX, USA*). We have seen many, many changes in the management of the myocardium during the era of open heart surgery. I believe one of the contraindications to intermittent occlusion is the presence of arteriosclerotic disease in the ascending aorta. In these circumstances, one cross-clamp may be devastating, and multiple cross-clamps should cause a serious arteriosclerotic embolism.

Another problem in intracardiac surgery arises when one subjects the patient more extensively to air embolism. In my opinion, one of the advantages of cardioplegia is that it controls air embolism.

It's interesting to see how the pendulum has swung back and forth as surgeons have continually sought ways to protect the myocardium. At one time emphasis was upon maintaining myocardial hypothermia, which led, in some cases, to bilateral phrenic palsy as a result of cold injury of the phrenic nerves. Excessive cold could also injure the myocardium.

In addition, I am concerned about the use by many surgeons of retrograde perfusion of the coronary circulation. I question the physiological soundness of that theory. Although retrograde perfusion is currently in vogue, the verdict is still out.

Finally, the addition of various drugs into the perfusate or into the cardioplegic solution is being explored extensively. Many of these substances are actually toxic to the myocardium, just as potassium citrate in large quantities was toxic when Dennis Melrose first introduced it some 35 years ago. I would caution those who keep modifying the solutions being used for myocardial preservation.

I congratulate the speaker on returning to what is more physiological than the modalities or techniques that have been used in the past 30 years. Thank you.

Dr. Antunes: I am flattered by your comments. I think you raised very good points. Time does not allow me to reply. Thank you.